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AD-A135 862

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TRANSIENT CURRENT DENSITY WAVEFORMS ON A PERFECTLY CONDUCTING SPHERE

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Technical Report 710816-13

Contract N00014-78-C-0049

October 1983

Department of the Navy
Office of Naval Research
800 N. Quincy Street
Arlington, Virginia 22217

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50272-101

REPORT DOCUMENTATION PAGE

1. Report No. AD-A135 862

2.

3. Recipient's Accession No

4. Title and Subtitle

TRANSIENT CURRENT DENSITY WAVEFORMS ON A PERFECTLY CONDUCTING SPHERE

5. Report Date: January 1983

6.

7. Author(s): E.M. Kennaugh and D.L. Moffatt

8. Performing Organization Rept. No. ESL 710816-13

9. Performing Organization Name and Address

The Ohio State University ElectroScience Laboratory
Department of Electrical Engineering
Columbus, Ohio 43212

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No

(C)

(G) N00014-78-C-0049

12. Sponsoring Organization Name and Address

Department of the Navy, Office of Naval Research
800 North Quincy Street (614 A:CEA)
Arlington, Virginia 22217

13. Type of Report & Period Covered: Technical Report

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

The time-dependent surface current density waveforms at various points on the surface of a perfectly conducting sphere illuminated by a plane electromagnetic wave are presented. The incident plane wave has an impulsive or shock-type time dependence. Current density waveforms in the E-plane (strong creeping wave) and H-plane on both the "lit" and shadowed sides of the sphere are shown. On the illuminated side of the sphere, removal of the Kirchhoff or physical optics approximation for the surface current density permits a detailed examination of the deficiencies of this approximation for short times (high frequencies). From these results the form of a first order correction to the Kirchhoff current is suggested. On the shadowed side of the sphere, the changing character of the current waveform is noted.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

19. Security Class (This Report): Unclassified

20. Security Class (This Page): Unclassified

21. No. of Pages: 34

22. Price

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

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I. INTRODUCTION

Development of the impulse response concept in 3-dimensional electromagnetic scattering problems [1,2] was materially aided by a Fourier synthesis procedure whereby harmonically related complex scattering data were used to synthesize approximate far-zone canonical response waveforms [2,3,4,5]. The same procedure permits one to generate the time-dependent surface current density waveforms on a scatterer or radiator. A comparison of Fourier synthesis and space-time integral equation calculations has been made[6]. Both procedures have an inherent resolution limitation dictated either by a finite summation (Fourier synthesis) or a Gaussian pulse excitation (space-time integral equation), but it is not correct to suggest that an infinite summation [7] or equivalently an impulsive excitation must be used. However, some care must be exercised in interpreting singularities and/or jump discontinuities particularly if they occur simultaneously.

Impetus for this report stems from a depolarization correction to physical optics derived by Bennett [8] and utilized by Boerner [9]. We show that even for an object where no depolarization occurs (the conducting sphere), the form of a basic correction to the Kirchhoff current can be deduced. It is suggested that similar first order corrections will improve the Kirchhoff approximation for a number of different object geometries.

A. Surface Current Density Waveforms

Mie series calculations of the tangential magnetic field and radial electric field at the surface of a conducting sphere of radius a immersed in an incident plane wave have been made for sphere circumferences in wavelengths of 0.2 (0.2)20.0. Locations on the sphere surface in both the E-plane and H-plane for theta angles of 0 (15) 180 degrees were used with 0 degrees corresponding to the specular point. The real, time-dependent surface current density waveforms synthesized from these data are shown in Figures 1, 2 and 3. Figure 1 combines the E-plane (positive) and H-plane (negative) waveforms on the illuminated side of the sphere. The abscissa scale is in units of transit time for the sphere diameter. On the illuminated side of the sphere, the weighted quasi-impulses at the origin of each waveform illustrate the resolution obtained (approximately o.75a). On the illuminated side of the sphere, the H-plane waveforms have a sign reversal. On the illuminated side of the sphere, the current density is primarily impulsive; details for short times are best seen after the Kirchhoff approximation for the current is removed. There is clear evidence of the creeping wave contributions. The surface current density waveforms on the shadowed side of the sphere are shown in Figure 2 (E-plane) and Figure 3 (H-plane). Note that the ordinate scales for H-plane are not constant. On the shadowed side of the sphere note that the character of the current density at the onset of the waveform is still apparently impulsive near the shadow boundary

(theta less than 120 degrees) in the H-plane but not in the E-plane. There is a strong creeping wave contribution in the E-plane and some evidence of a very weak creeping wave contribution in the H-plane.

In Figure 4 the surface current density waveforms on the illuminated side of the sphere are shown after the Kirchhoff approximation to the current density has been removed. The H-plane waveforms are dashed. It is very evident that as the observation point progresses from the specular point to the shadow boundary, the Kirchhoff approximation becomes progressively too large in the E-plane and too small in the H-plane. At a given angle, the magnitude of the errors in the E-plane and H-plane are approximately equal. This would seem to imply that on a cut at 45 degrees from the E-plane and H-plane the Kirchhoff approximation to the current may be quite good even near the shadow boundary. In the E-plane at theta equal 60 degrees and 75 degrees one can also clearly discern two distinct creeping wave contributions, both launched from the shadow boundary and delayed from the waveform onset by different travel times on the sphere surface.

B. Correction

Based on the results shown for the conducting sphere, the following formulas for correcting the physical optics estimates for the induced currents are suggested for smooth (no edge) scatterers. In the E-plane modify the physical optics currents by the multiplicative factor

$$[1 - K \sin\theta] \quad . \tag{1}$$

In the H-plane modify the physical optics currents by the multiplicative factor

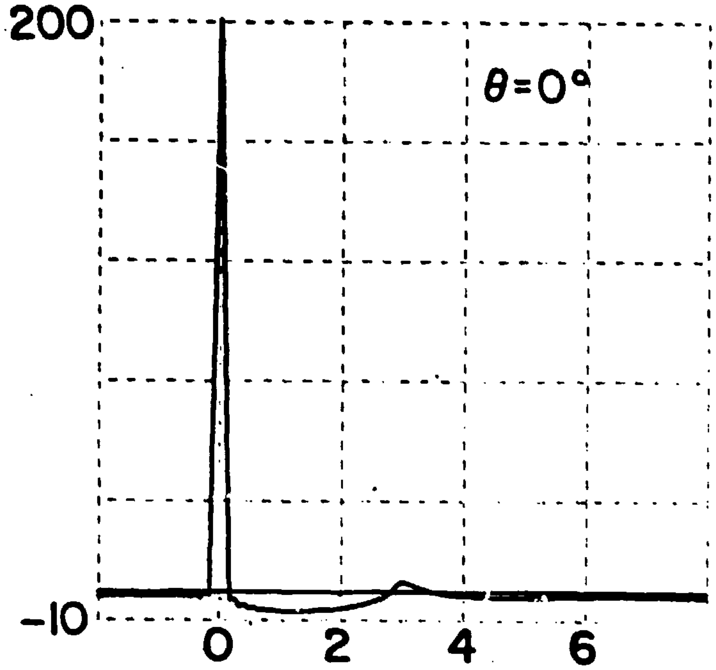
$$[1 + K \frac{\sin\theta}{\cos\theta}] \quad , \tag{2}$$

where θ is the angle between the outward normal to the surface of scatterer and the backscatter direction. The H-plane correction becomes infinite at the shadow boundary (θ=90°) but when multiplied by the physical optics current estimate ($\cos\theta$ factor) yields a finite current estimate. The specular error (exact minus physical optics) before correction is shown in Figure 5. Figures 6 and 7 show the effect of the correction term for values of the constant K of 0.2 and 0.1, respectively. For the simple form of the correction suggested, a value K near 0.1 appears optimum. Other forms for the correction, possibly exponential, may suggest themselves to the reader. Our purpose here, however, was to show that simple corrections are possible.

C. Conclusions

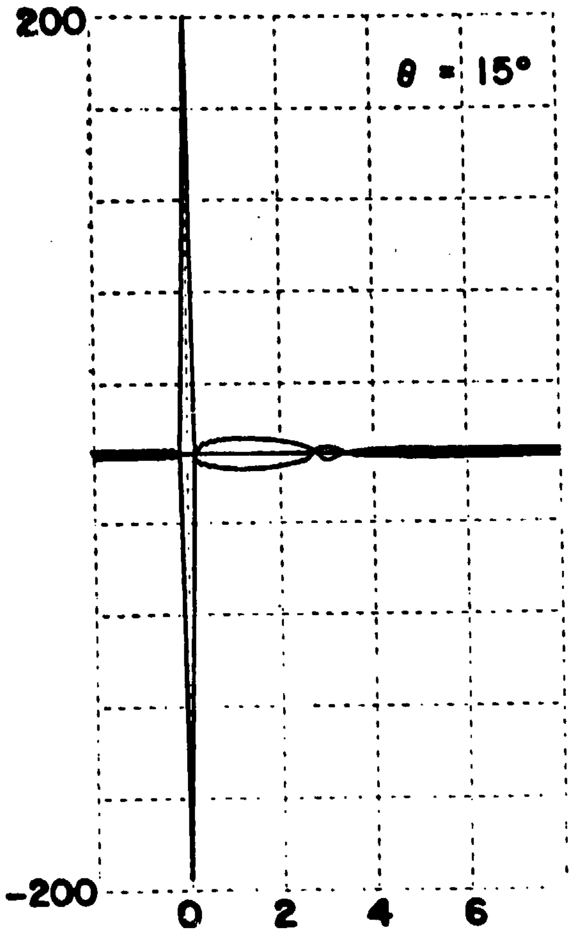
It has been demonstrated that relatively simple formulas can be developed for correcting the physical optics estimates of the current densities induced on a conducting spherical scatterer. It has also been suggested that similar simple corrections could be made for other "smooth" scatterers. It is noted that the corrections indicated here are not related to depolarization properties of the scatterer.

The surface current density waveforms on the shadowed side of the sphere have been included here for the possible benefit of other researchers. The physical optics estimate has long been a favorite direct scattering solution for inverse scattering because the estimate can be generally related to a target cross sectional area function on the illuminated side of the scatterer. A similar relationship (general) for the shadowed side of the scatterer would greatly improve imaging techniques based on the physical optics estimate.



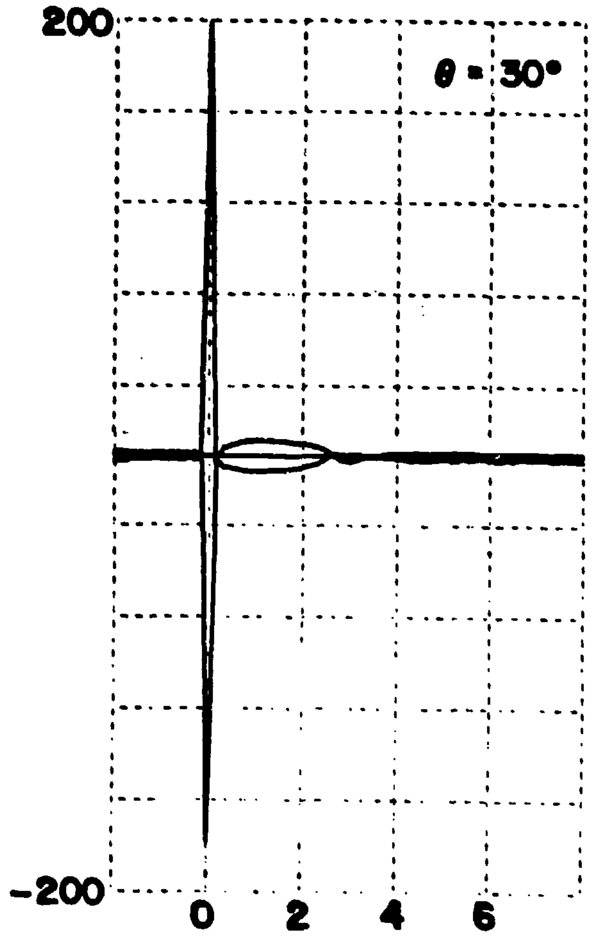
a. θ = 0° (specular)

Figure 1. E-plane (positive) and H-plane (negative) surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Illuminated side of sphere.



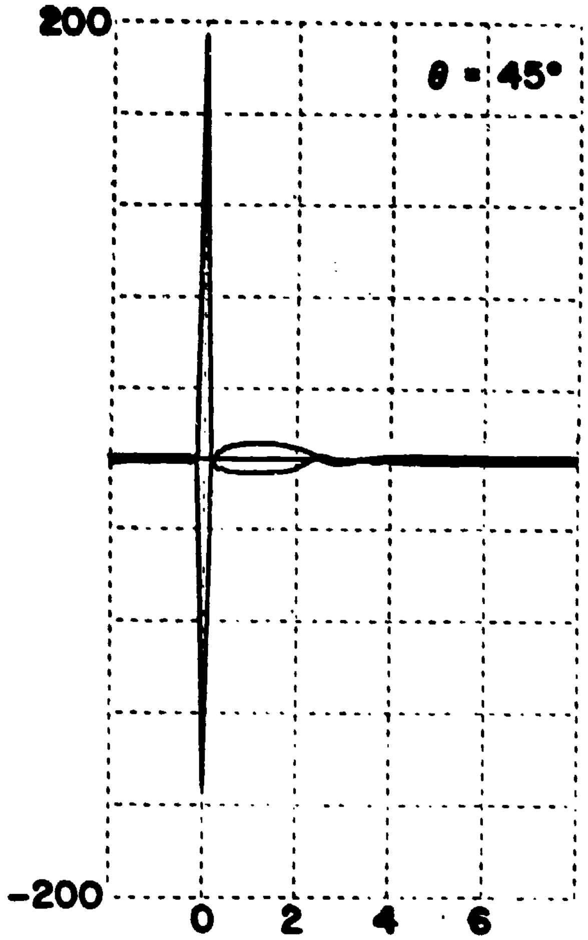
b. θ = 15°

Figure 1. E-plane (positive) and H-plane (negative) surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Illuminated side of sphere.



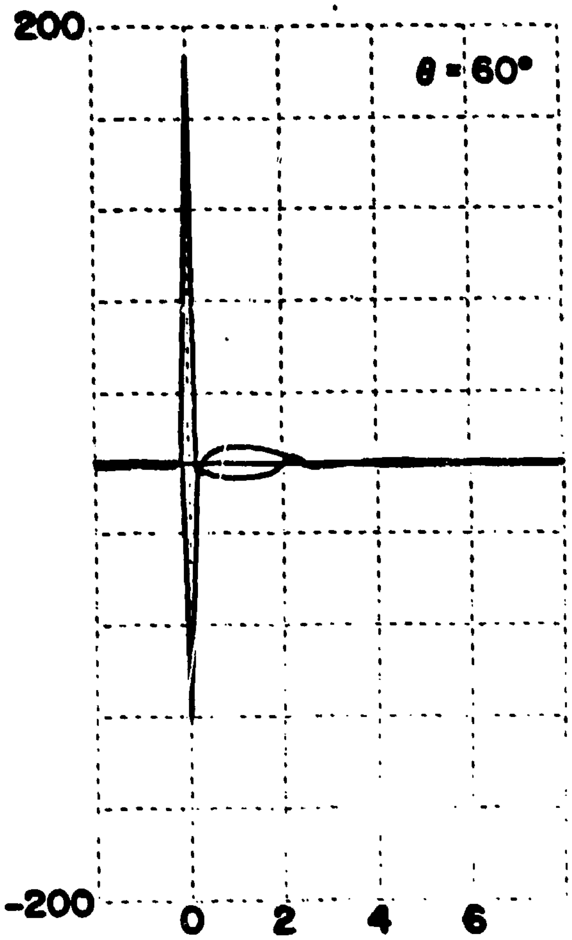
c. θ = 30°

Figure 1. E-plane (positive) and H-plane (negative) surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Illuminated side of sphere.



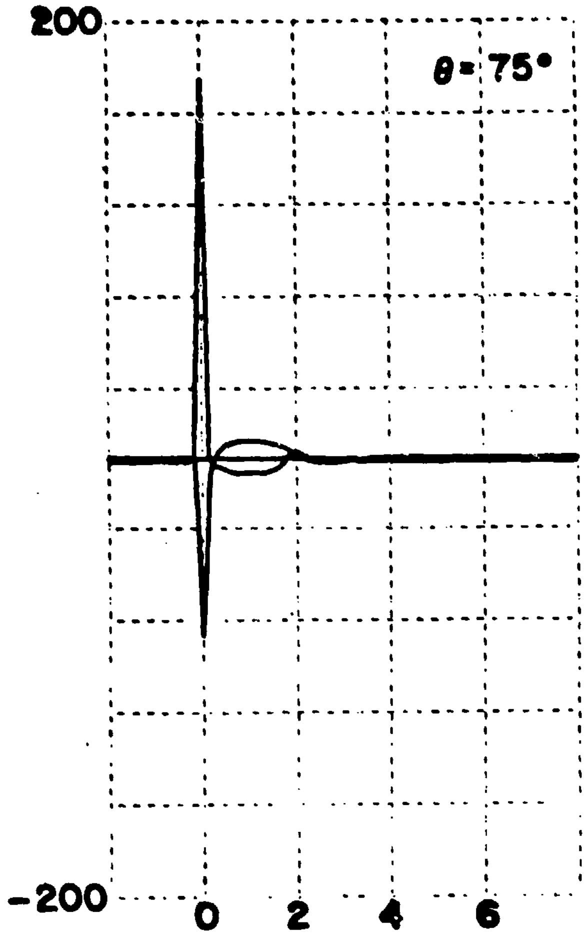
d. θ = 45°

Figure 1. E-plane (positive) and H-plane (negative) surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Illuminated side of sphere.



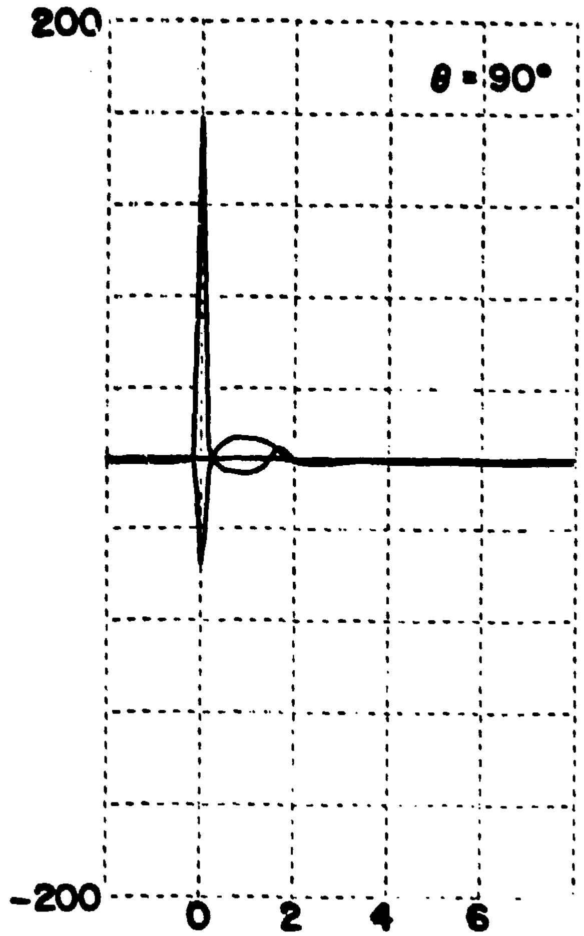
e. θ = 60°

Figure 1. E-plane (positive) and H-plane (negative) surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Illuminated side of sphere.



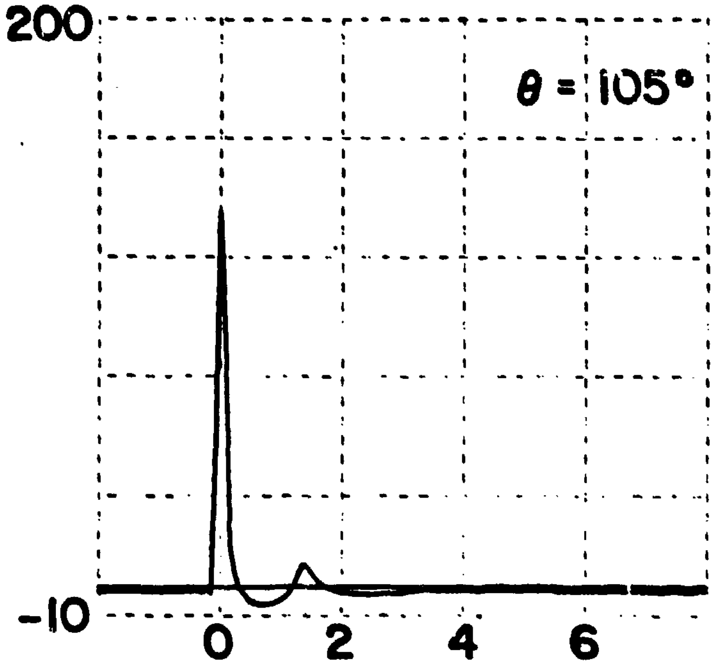
f. θ = 75°

Figure 1. E-plane (positive) and H-plane (negative) surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Illuminated side of sphere.



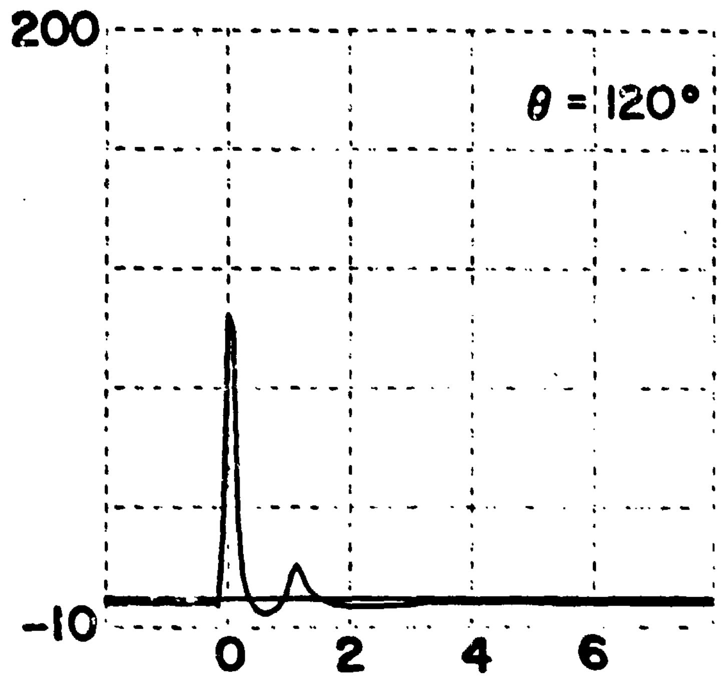
g. θ = 90°

Figure 1. E-plane (positive) and H-plane (negative) surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Illuminated side of sphere.



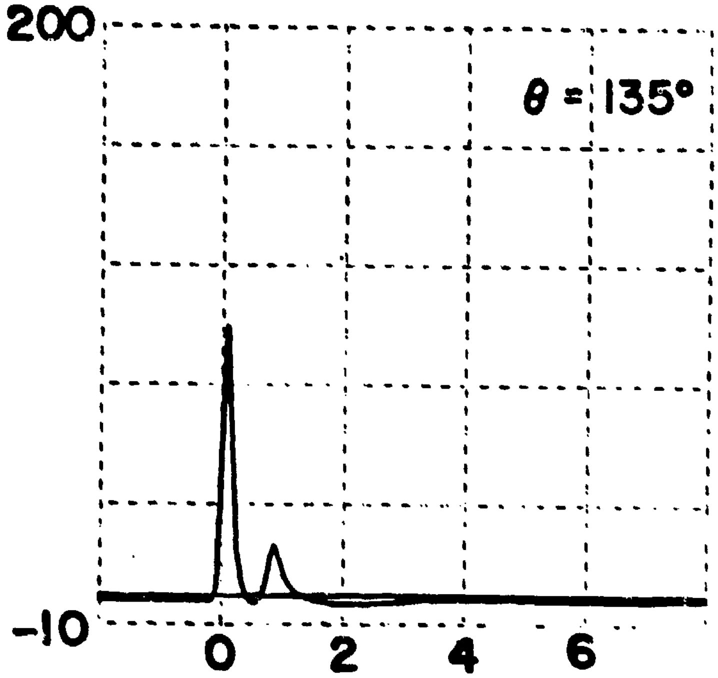
a. θ = 105°

Figure 2. E-plane surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Shadowed side of sphere.



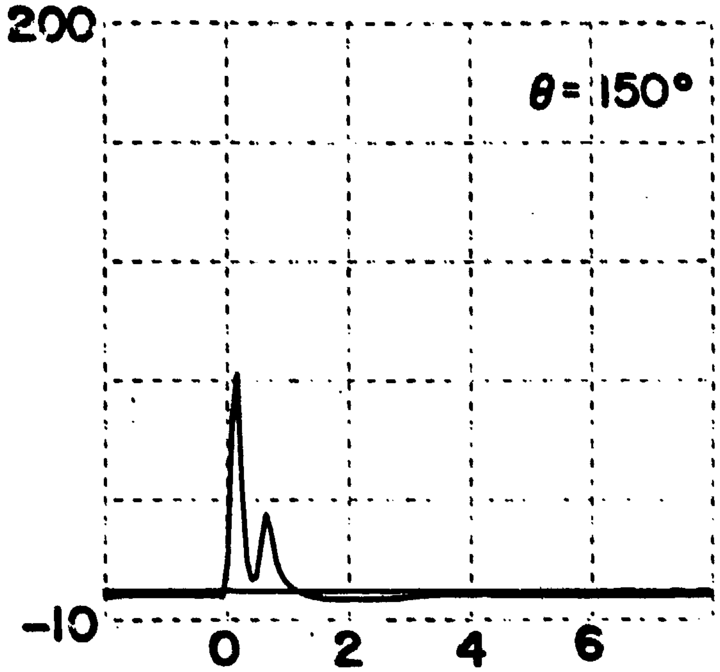
b. θ = 120°

Figure 2. E-plane surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Shadowed side of sphere.



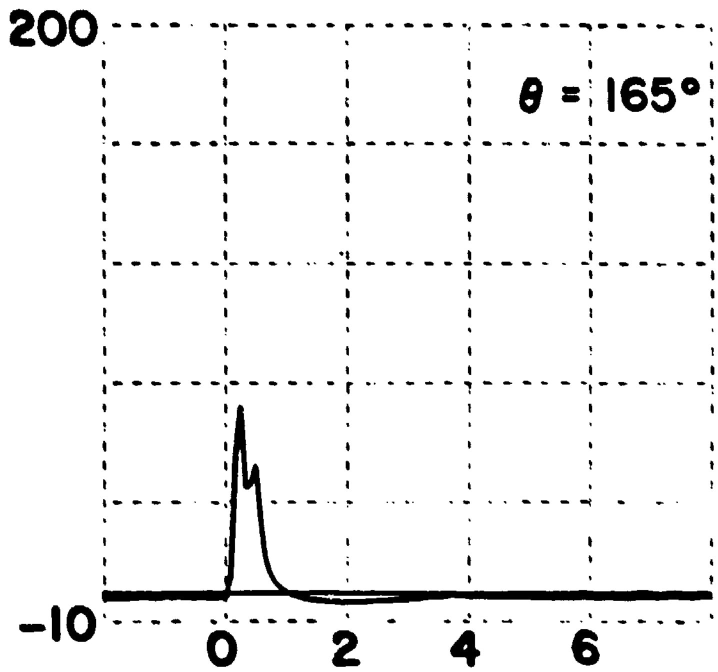
c. θ = 135°

Figure 2. E-plane surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Shadowed side of sphere.



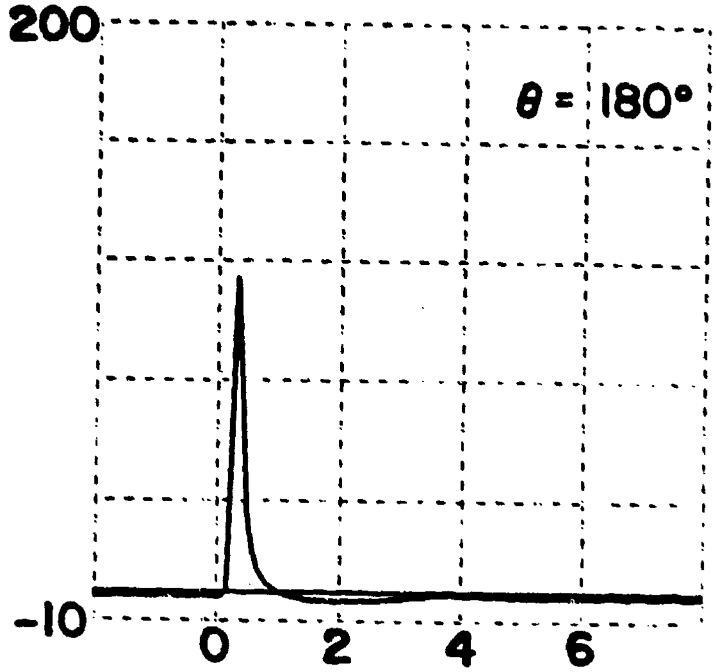
d. θ = 150°

Figure 2. E-plane surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Shadowed side of sphere.



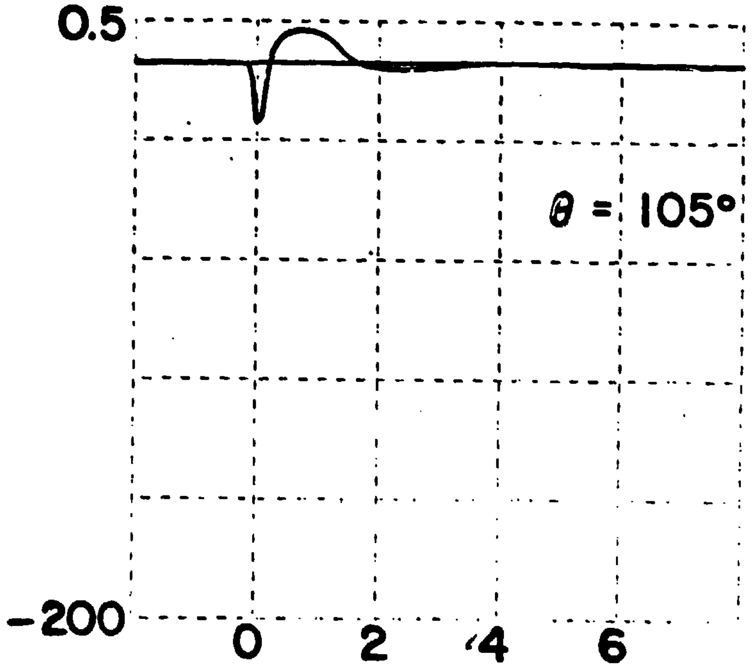
e. θ = 165°

Figure 2. E-plane surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Shadowed side of sphere.



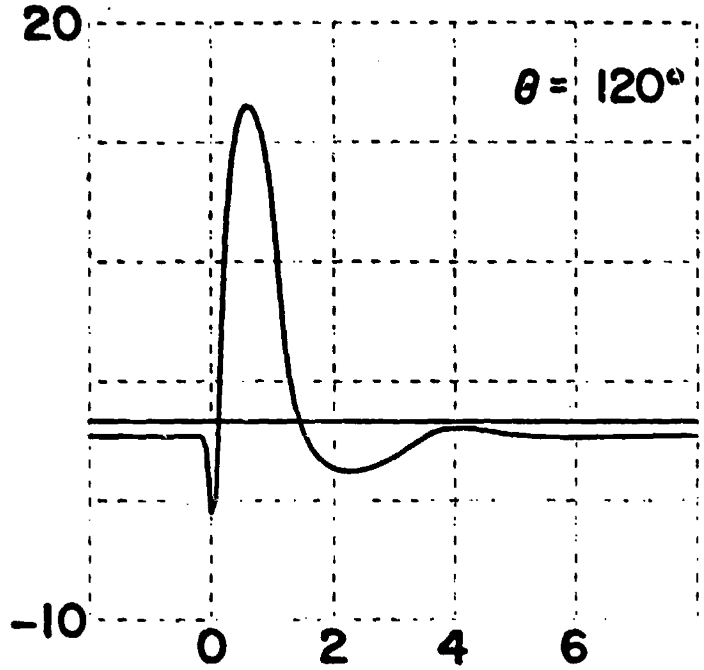
f. θ = 180°

Figure 2. E-plane surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Shadowed side of sphere.



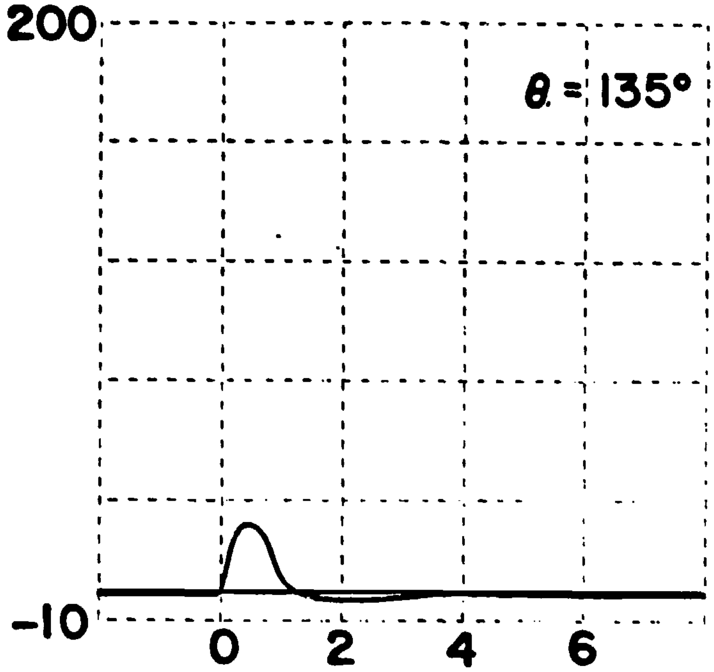
a. θ = 105°

Figure 3. H-plane surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Shadowed side of sphere.



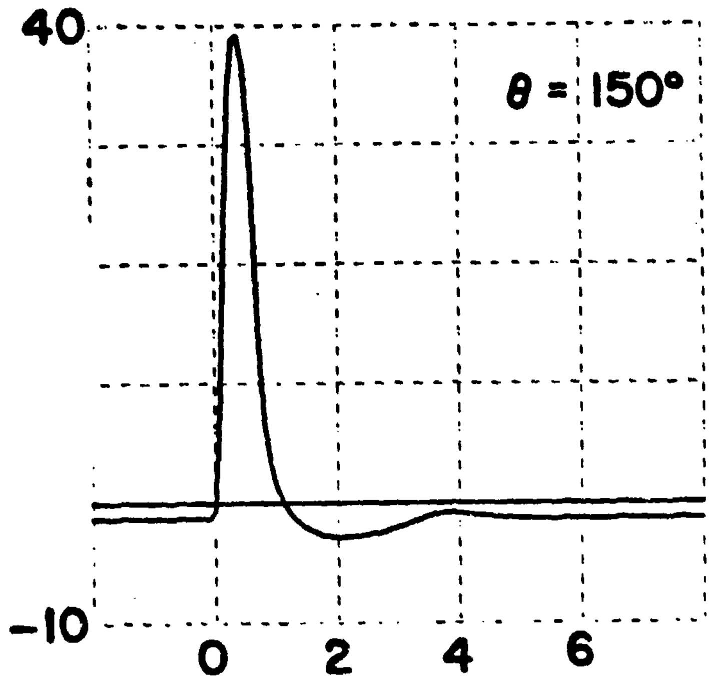
b. θ = 120°

Figure 3. H-plane surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Shadowed side of sphere.



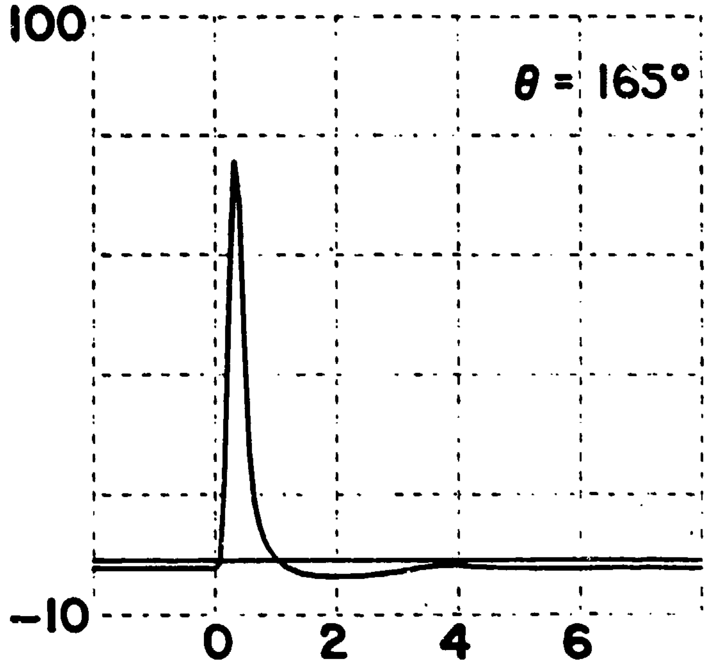
c. θ = 135°

Figure 3. H-plane surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Shadowed side of sphere.



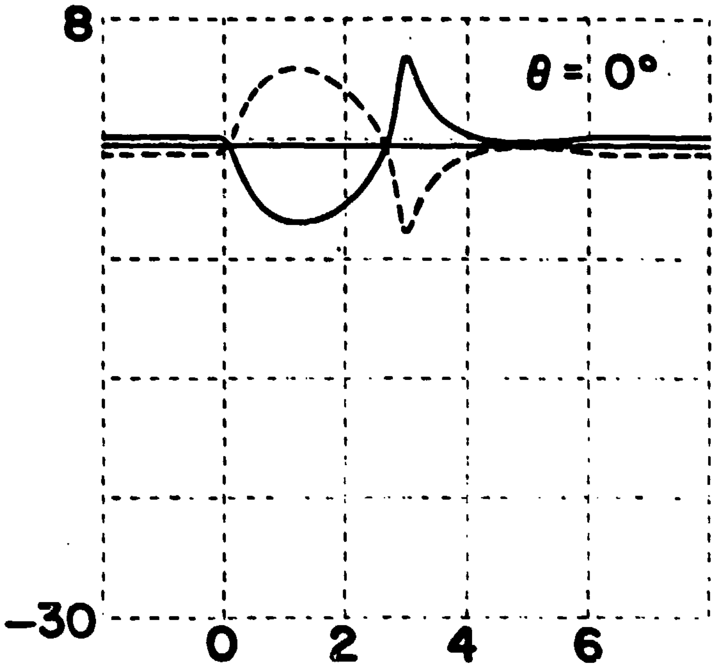
d. $\theta = 150°$

Figure 3. H-plane surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Shadowed side of sphere.



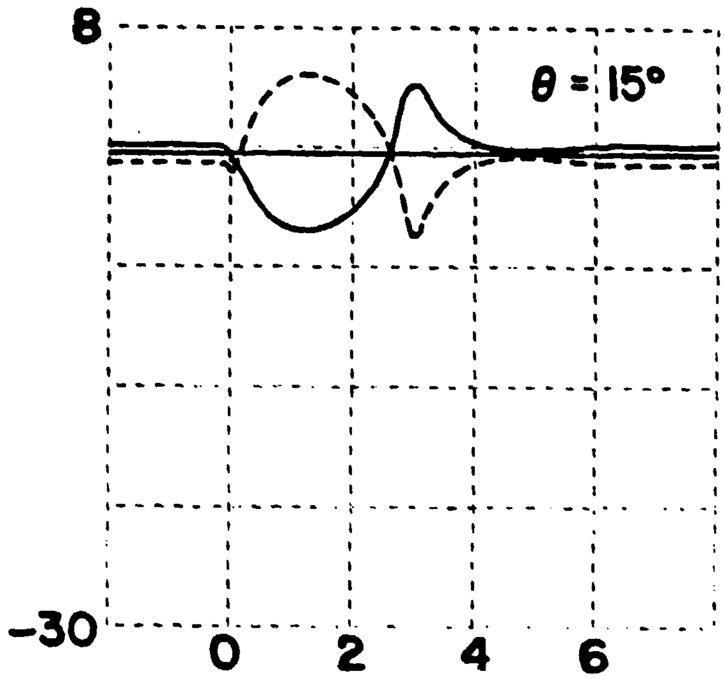
e. θ = 165°

Figure 3. H-plane surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere. Shadowed side of sphere.



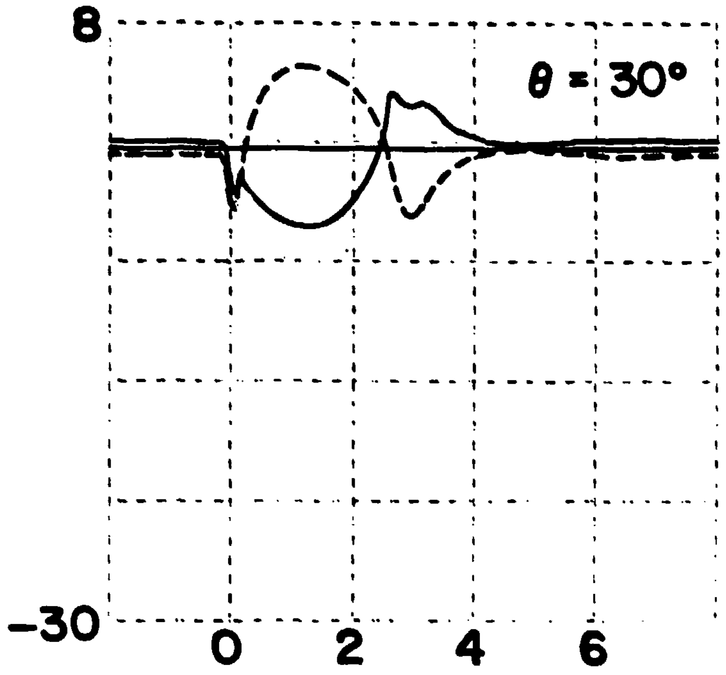
a. θ = 0°

Figure 4. E-plane (solid) and H-plane (dashed) surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere after the physical optics approximation for the surface current density has been removed. Illuminated side of sphere.



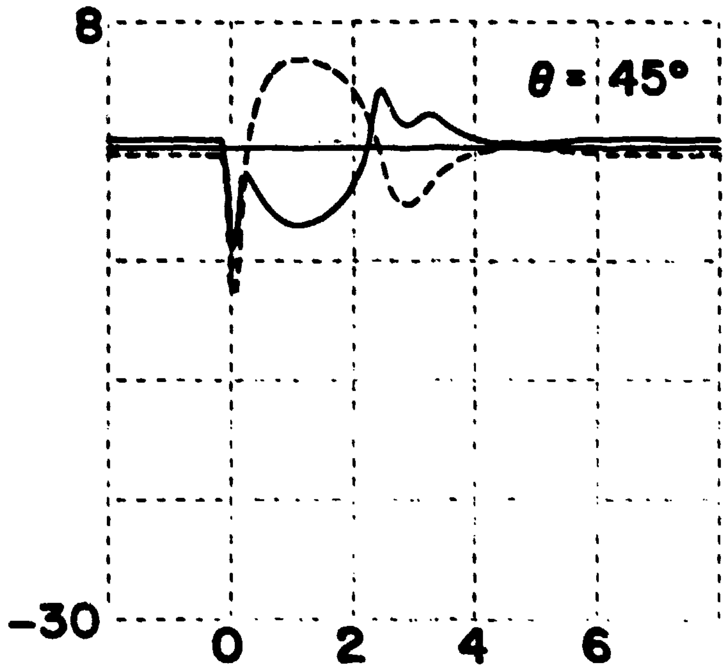
b. θ = 15°

Figure 4. E-plane (solid) and H-plane (dashed) surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere after the physical optics approximation for the surface currrent density has been removed. Illuminated side of sphere.



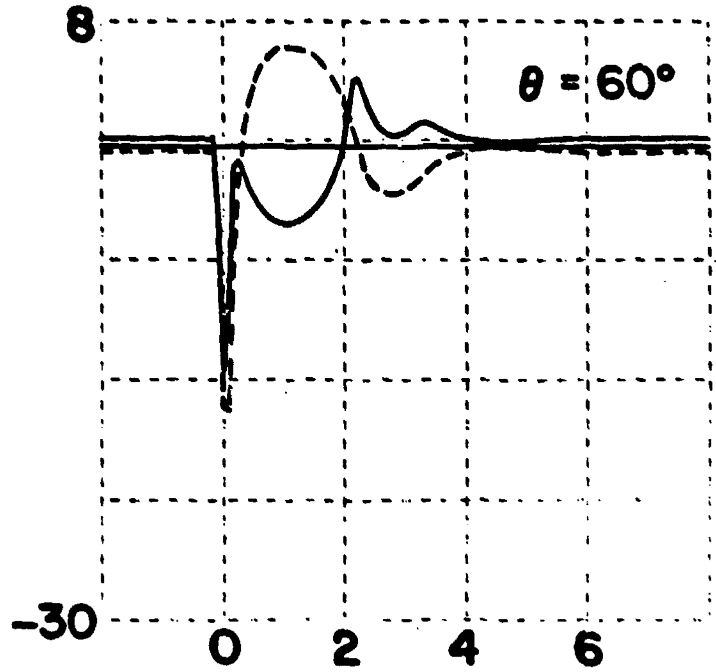
c. θ = 30°

Figure 4. E-plane (solid) and H-plane (dashed) surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere after the physical optics approximation for the surface current density has been removed. Illuminated side of sphere.



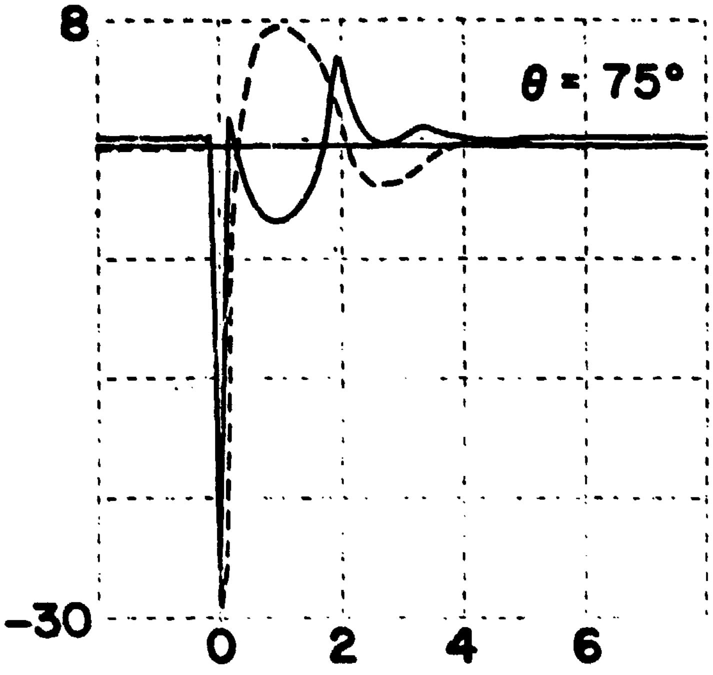
d. θ = 45°

Figure 4. E-plane (solid) and H-plane (dashed) surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere after the physical optics approximation for the surface current density has been removed. Illuminated side of sphere.



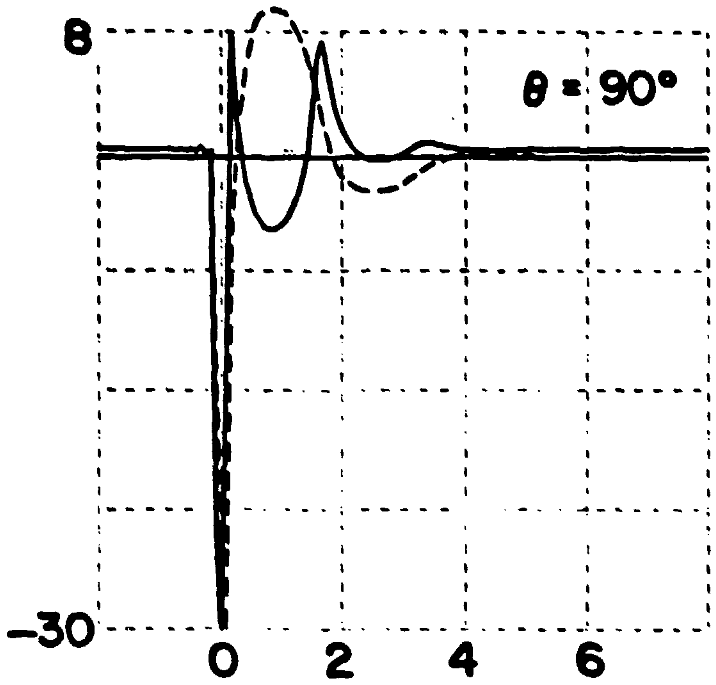
e. θ = 60°

Figure 4. E-plane (solid) and H-plane (dashed) surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere after the physical optics approximation for the surface current density has been removed. Illuminated side of sphere.



r. θ = 75°

Figure 4. E-plane (solid) and H-plane (dashed) surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere after the physical optics approximation for the surface current density has been removed. Illuminated side of sphere.



g. θ = 90°

Figure 4. E-plane (solid) and H-plane (dashed) surface current density waveforms induced by an impulsive plane wave on a perfectly conducting sphere after the physical optics approximation for the surface current density has been removed. Illuminated side of sphere.

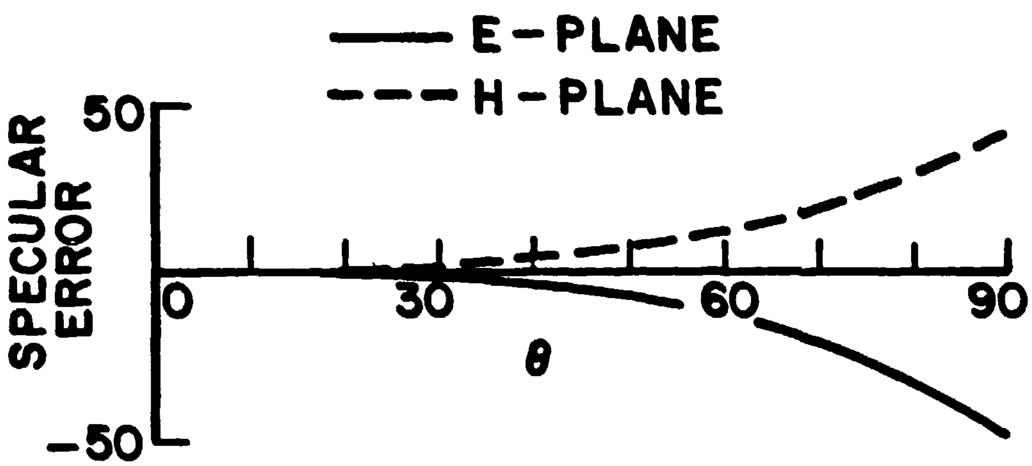


Figure 5. E-plane (solid) and H-plane (dashed) error for specular term (exact minus physical optics) for surface current density induced by an impulsive plane wave on a perfectly conducting sphere.

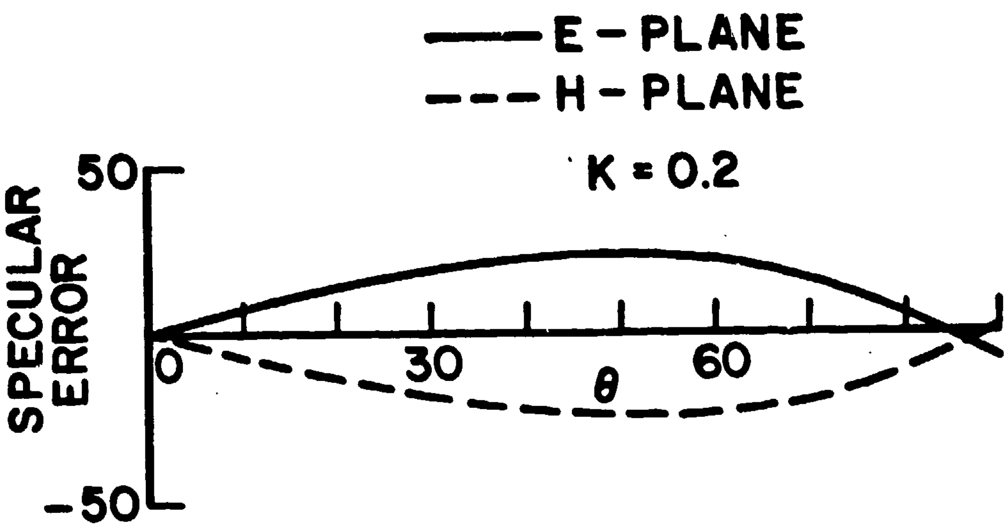


Figure 6. E-plane (solid) and H-plane (dashed) error for specular term (exact minus corrected physical optics, value of K constant is 0.2) for surface current density induced by an impulsive plane wave on a perfectly conducting sphere.

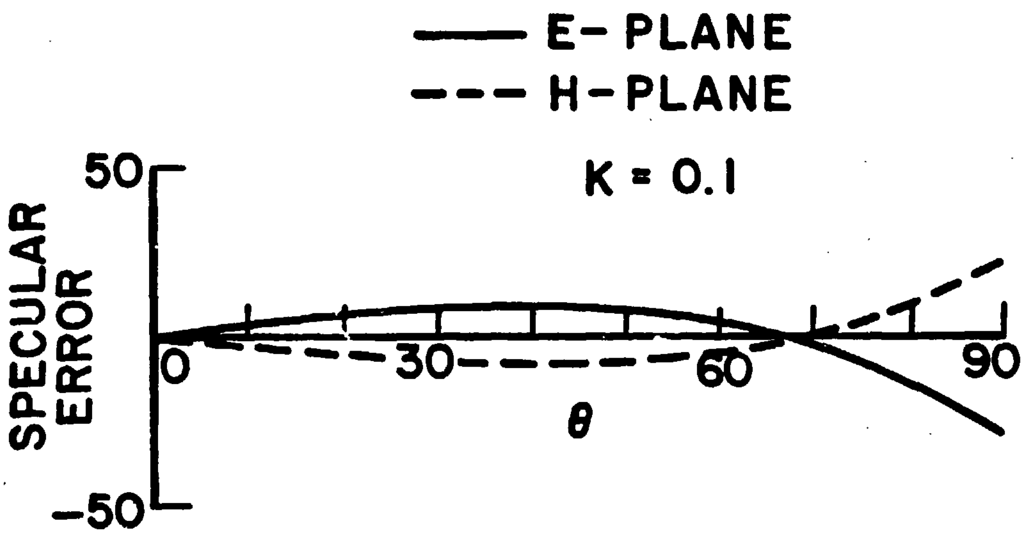


Figure 7. E-plane (solid) and H-plane (dashed) error for specular term (exact minus corrected physical optics, value of K constant is 0.2) for surface current density induced by an impulsive plane wave on a perfectly conducting sphere.

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